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2017-03-02

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JAMA Psychiatry. 2015 Oct;72(10):971-8.

<http://doi.org/10.1001/jamapsychiatry.2015.1165>

<http://hdl.handle.net/10616/45558>

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Original Investigation

A Longitudinal Study of Resting Heart Rate and Violent Criminality in More Than 700 000 Men

Antti Latvala, PhD; Ralf Kuja-Halkola, PhD; Catarina Almqvist, PhD; Henrik Larsson, PhD; Paul Lichtenstein, PhD

IMPORTANCE Low resting heart rate is a well-replicated physiological correlate of aggressive and antisocial behavior in children and adolescents, but whether low resting heart rate increases the risk of violence and other antisocial and risk-taking behaviors in adulthood has not been studied in representative samples.

OBJECTIVE To study the predictive association of resting heart rate with violent and nonviolent criminality and with fatal and nonfatal injuries owing to assaults and unintentional injuries in the population.

DESIGN, SETTING, AND PARTICIPANTS We conducted a study of data from several Swedish national registers on 710 264 Swedish men in the general population born from 1958 to 1991, with a follow-up of up to 35.7 years. Outcome data were available and analyzed from January 1, 1973, through December 31, 2009. Resting heart rate was measured together with blood pressure at mandatory military conscription testing at a mean (SD) age of 18.2 (0.5) years.

MAIN OUTCOMES AND MEASURES Violent and nonviolent criminal convictions and medical treatments or deaths owing to assaults and unintentional injuries.

RESULTS In models adjusted for physical, cardiovascular, psychiatric, cognitive, and socioeconomic covariates, compared with 139 511 men in the highest quintile of the distribution of resting heart rate (≥ 83 beats/min), 132 595 men with the lowest quintile (heart rate, ≤ 60 beats/min) had a 39% (95% CI, 35%-44%) higher hazard of being convicted of violent crimes and a 25% (95% CI, 23%-28%) higher hazard of being convicted of nonviolent crimes. The corresponding hazard was 39% higher for assault injuries (95% CI, 33%-46%) and for unintentional injuries (95% CI, 38%-41%). Further adjustment for cardiorespiratory fitness in a subset of 572 610 men with data from an exercise test did not reduce the associations. Similar associations were found between low systolic blood pressure and violent and nonviolent criminality and for assault injuries when systolic blood pressure was studied instead of resting heart rate in more than 1 million men.

CONCLUSIONS AND RELEVANCE Among men, low resting heart rate in late adolescence was associated with an increased risk for violent criminality, nonviolent criminality, exposure to assault, and unintentional injury in adulthood. Most of these results were replicated with low systolic blood pressure. Resting heart rate and other autonomic measures merit further study in the development and prevention of violence and antisocial behavior.

JAMA Psychiatry. 2015;72(10):971-978. doi:10.1001/jamapsychiatry.2015.1165
Published online September 9, 2015.

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An estimated 1.2 million violent crimes occurred in 2013 in the United States alone, corresponding to a rate of 368 crimes per 100 000 inhabitants.¹ Despite the high cost of violence,² its prevention has been unsuccessful compared with the prevention of other health risks.³ A better understanding of individual-level biological risk factors in the etiology of violence could help prevention and intervention efforts by allowing for early identification of people with an elevated risk of violent behaviors.

Low resting heart rate (RHR) is the best-replicated physiological correlate of antisocial behavior in children and adolescents.^{4,5} Findings from 2 meta-analyses have confirmed that antisocial or aggressive children and adolescents have a lower RHR than do their peers without antisocial tendencies.^{6,7} Low RHR has been viewed either as an indicator of a chronically low level of physiological arousal, which may lead individuals to seek stimulating experiences to increase their arousal, or as a marker of attenuated responses to aversive and stressful stimuli, leading to fearless behavior and risk taking.^{5,8,9}

Not much is known about RHR as a predictor of severe violence in adulthood. In a meta-analysis, Lorber⁶ identified 6 studies of aggressive behavior in adults and found an association with low RHR. The studies were based on small and select samples, with an average of 43 participants per study. A small number of longitudinal studies have found a predictive association between low RHR and criminality later in adulthood, but they too have been based on select samples, whereas no representative, population-based studies exist.¹⁰⁻¹³

The association between RHR and risk of violence in the general adult population is thus uncertain. It is also unclear whether nonviolent antisocial behaviors and other behavioral outcomes of fearlessness or stimulation-seeking tendencies are predicted by low RHR. Previous evidence on the association between RHR and different types of criminality in adulthood is scarce,¹² and, to our knowledge, no research on the association between RHR and real-life outcomes of risk-taking behaviors, such as unintentional injuries, has been conducted despite the well-known association between stimulation-seeking tendencies and risky behavior.¹⁴

We conducted a large-scale epidemiologic study on the predictive association between RHR assessed in late adolescence and violent criminality later in life using population-based data on men with a follow-up of up to 35.7 years. We also tested whether RHR predicted nonviolent crimes and injuries owing to risk-taking as a result of fearlessness or stimulation seeking.

Methods

Study Population

Outcome data were available and analyzed from January 1, 1973, through December 31, 2009. We linked several Swedish national registers maintained by governmental agencies with longitudinal data available until December 31, 2009. A unique personal identification number, given to all citizens at birth, was used as a key in the register linkages. Resting heart rate was mea-

sured during a 2-day conscription assessment for the Swedish Armed Forces, mandatory until 2009 for all Swedish men at age 18 years. Only men with severe diseases, physical disabilities, or mental retardation were exempt, and more than 95% of men generally attended the conscription assessment.¹⁵ Combining information from the Total Population Register and the Conscription Register, we identified all men who were born in Sweden between 1958 and 1991 and conscripted by December 31, 2009 (N = 1 488 886). The Multi-Generation Register¹⁶ was used to identify the biological parents of each individual. Those who had missing information on either parent's identity were excluded from the study (n = 16 413). We also excluded men who, on the basis of the Migration Register, had emigrated from Sweden before conscription (n = 15 231). The sample thus included 1 457 242 men. The study was approved by the Karolinska Institutet Institutional Review Board.

RHR and Outcome Measures

Resting heart rate was measured in the conscription examination together with blood pressure. A standardized procedure was used to measure blood pressure with an appropriately sized cuff at heart level after 5 to 10 minutes of rest while the individual was in the supine position.¹⁷ Resting heart rate values below 35 beats/min and above 145 beats/min were excluded as outliers or possible data errors (n = 138; these cut-offs excluded the bottom and top 0.01% of the RHR distribution). Possibly owing to changes in the registering procedures, RHR values were nearly completely missing from the Conscription Register for the years 1984 to 1993, and data coverage also varied during other periods. As a result, a valid RHR value was available for 710 264 men (49% of the full cohort). Sensitivity analyses were conducted to assess the effect of missing RHR data.

Information about violent and nonviolent criminal convictions was obtained from the Crime Register, which contains all convictions in lower courts for individuals aged 15 years (the age of criminal responsibility in Sweden) and older from 1973 onward. Violent crimes included convictions of murder, manslaughter, assault, kidnapping, illegal restraint, illegal coercion or threats, robbery, threats or violence against an officer, arson, gross violation of a person's integrity, and harassment, as well as any sexual crimes. Nonviolent crimes included drug-related crimes, property crimes, and traffic crimes (excluding speeding and parking fines issued by a police officer).

As secondary outcomes, we studied injuries whose risk we hypothesized to be elevated as a result of fearless or stimulation-seeking behaviors. The injury outcomes were inpatient or outpatient treatments and deaths owing to assaults (*International Classification of Diseases, Eighth Revision [ICD-8]* codes E960-E968; *ICD-9* codes E960-E968; and *ICD-10* codes X85-Y09) and unintentional injuries (*ICD-8* codes E800-E929; *ICD-9* codes E800-E869 and E880-E928; and *ICD-10* codes V01-X59). Assaults include, for example, death by homicide as well as assaults by firearms, motor vehicles, or other objects. Unintentional injuries include transportation crashes and other external causes of injury, such as falls, unintentional poisonings, and exposure to inanimate or animate mechanical forces.

The injury data were available from the Patient Register, which contains details of all individual episodes of hospitalization in Sweden since 1973 and outpatient treatment since 2001, and from the Cause of Death Register.

Covariates

As covariates, we included factors that could confound the association between RHR and the studied outcomes. Height, weight, and body mass index were included because they could influence both cardiovascular functioning and the risk for criminality.¹⁸ Diastolic blood pressure was included as an indicator of cardiovascular health. We also included information on the history of inpatient or outpatient treatment for psychiatric disorders (*ICD-8* codes 290-315; *ICD-9* codes 290-319; and *ICD-10* codes F00-F99), available from the Patient Register, and general cognitive ability (IQ), available from the conscription testing data as assessed with the Swedish Enlistment Battery.¹⁵ Family socioeconomic status (SES) before age 10 years was available from national censuses in 1960, 1970, 1980, 1985, and 1990. The SES variable was derived from the occupation of the head of the household (usually the father) and coded into 3 classes: low (skilled and unskilled workers across all fields), medium (low- and intermediate-position white-collar workers), and high (high-position white-collar workers and self-employed professionals and entrepreneurs). Because RHR correlates with cardiorespiratory fitness, which could potentially influence the risk of criminal convictions and injuries, we also adjusted for maximal workload achieved in an exercise test with a cycle ergometer during the conscription testing.¹⁹ Maximal workload test results were available for 572 610 men with a nonmissing RHR value. The maximal workload value was divided by weight to take into account the effect of body size. Birth and conscription years were included to adjust for potential cohort and period effects.

Statistical Analysis

We conducted Cox proportional hazards regression models to estimate the relative hazard of violent crime and other outcomes across the studied age period starting from the month of conscription. The crime and injury outcomes were analyzed separately, and only outcomes occurring after conscription were included in the primary analyses. The participants were followed up until the first occurrence of the respective outcome. Those for whom the studied outcome did not occur within the study period contributed person-time at risk until the end of follow-up (December 31, 2009), emigration, or death, whichever occurred first.

In the main analyses, we conducted 4 Cox proportional hazards regression models for each outcome using a quintile categorization of RHR. We chose quintile categorization as an illustrative way to analyze the associations while allowing for potential nonlinearity. Graphical inspection of the Schoenfeld residuals for RHR did not reveal violations of the Cox proportional hazards assumption. The first model adjusted only for birth and conscription years. The second model included physical and cardiovascular covariates, and the third model added psychiatric disorders, IQ, and childhood SES. The fourth model also adjusted for cardiorespira-

tory fitness in the subset of men with exercise test data. The models were conducted with adjustment of standard errors for the nonindependence of brothers using a robust sandwich estimator.

Further analyses were conducted to study the associations between RHR and specific types of crime. We classified violent crimes as severe or less severe based on whether they were associated with custodial sentences (imprisonment, forensic psychiatric inpatient care, or closed institutional youth care) or not, and conducted separate Cox proportional hazards regression models for the 2 types of severity. We also conducted separate Cox proportional hazards regression models for sexual crimes committed by men without nonsexual violence and for drug crimes, property crimes, and traffic crimes committed by men without violent convictions. A follow-up analysis of RHR and age at first conviction was also conducted among men who had their first violent conviction by the age of 40 years ($n = 27\,313$).

We conducted several sensitivity analyses to rule out possible alternative explanations. First, we tested the associations of RHR and crimes after excluding men who had any convictions before conscription to rule out the possibility that having conducted crimes could have influenced RHR. Second, because individuals with antisocial outcomes occurring later in life may have a partly different background than individuals with such outcomes occurring at a younger age, we investigated associations between RHR and crimes that took place before the age of 30 years. Third, to rule out any potential bias owing to time periods with low coverage for RHR data, we evaluated the associations with criminality using only data from the conscription years with more complete RHR coverage (determined by comparing the number of observations with nonmissing RHR values with other variables from the conscription). Furthermore, we compared men with and without an RHR value on the outcome measures and covariates. Finally, to complement missing RHR data and to replicate the results using another measure of autonomic functioning, we repeated the analyses using systolic blood pressure (SBP), known to correlate with RHR²⁰ and available from the conscription testing data for 1 222 567 men.

Results

Baseline characteristics of the 710 264 men with RHR data are presented in **Table 1**. Mean (SD) age at conscription was 18.2 (0.5) years and the mean (SD) RHR was 72.2 (12.8) beats/min. **Table 2** displays the rates of all studied outcomes by quintiles of RHR during follow-up. During 12 869 207 person-years of follow-up, 40 093 men were convicted of a violent crime. The mean (SD) follow-up was 18.1 (10.7) years for violent crimes, 16.1 (10.9) years for nonviolent crimes, 16.1 (10.8) years for unintentional injuries, and 18.7 (10.6) years for assault injuries. For all outcomes, the length of follow-up ranged from 1 month to 35.7 years. The **Figure** shows the Kaplan-Meier survival curves for violent criminality; curves for the other outcomes are in eFigures 1, 2, and 3 in the **Supplement**.

Table 1. Baseline Characteristics of Men by Quintiles of Resting Heart Rate

Variable	Resting Heart Rate Quintiles (Beats/min)					Total Sample
	1st (35-60)	2nd (61-67)	3rd (68-74)	4th (75-82)	5th (83-145)	
Men, No.	132 595	137 117	155 687	145 354	139 511	710 264
Age at conscription, mean (SD), y	18.2 (0.5)	18.2 (0.5)	18.2 (0.5)	18.2 (0.5)	18.2 (0.5)	18.2 (0.5)
Resting heart rate, mean (SD), beats/min	55.2 (4.3)	64.1 (2.0)	70.8 (2.0)	78.3 (2.3)	91.3 (7.9)	72.2 (12.8)
Height, mean (SD), cm ^a	180.1 (6.4)	179.8 (6.5)	179.7 (6.5)	179.6 (6.6)	179.3 (6.6)	179.7 (6.5)
Weight, mean (SD), kg ^b	71.6 (9.6)	71.3 (10.3)	71.3 (10.8)	71.5 (11.6)	71.9 (12.9)	71.5 (11.1)
BMI, mean (SD) ^c	22.1 (2.6)	22.0 (2.8)	22.0 (3.0)	22.2 (3.2)	22.3 (3.6)	22.1 (3.1)
Systolic blood pressure, mean (SD), mm Hg ^d	125.6 (10.6)	127.2 (10.5)	128.7 (10.5)	130.2 (10.5)	133.3 (10.8)	129.1 (10.9)
Diastolic blood pressure, mean (SD), mm Hg ^e	66.6 (9.0)	66.7 (9.0)	66.9 (9.2)	67.4 (9.4)	68.9 (9.8)	67.3 (9.3)
General cognitive ability, mean (SD), stanines ^f	5.3 (1.8)	5.3 (1.8)	5.2 (1.9)	5.2 (1.9)	5.2 (1.9)	5.2 (1.9)
Any psychiatric disorder, No. (%)	11 425 (8.6)	12 375 (9.0)	14 593 (9.4)	14 064 (9.7)	14 083 (10.1)	66 540 (9.4)
Childhood SES, No. (%)						
Low	49 768 (37.5)	53 192 (38.8)	61 892 (39.8)	58 494 (40.2)	57 823 (41.5)	281 169 (39.6)
Medium	49 419 (37.3)	49 526 (36.1)	55 048 (35.4)	50 527 (34.8)	47 014 (33.7)	251 534 (35.4)
High	27 278 (20.6)	27 889 (20.3)	31 557 (20.3)	29 941 (20.6)	28 857 (20.7)	145 522 (20.5)
Missing	6130 (4.6)	6510 (4.8)	7190 (4.6)	6392 (4.4)	5817 (4.2)	32 039 (4.5)
Maximal workload, mean (SD), W ^g	290.9 (48.2)	279.8 (48.2)	273.0 (47.8)	267.7 (47.8)	259.1 (45.8)	274.0 (48.7)

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); SES, socioeconomic status.

^d n = 707 398.

^e n = 709 034.

^f n = 707 035.

^g n = 572 610.

^a n = 709 143.

^b n = 709 052.

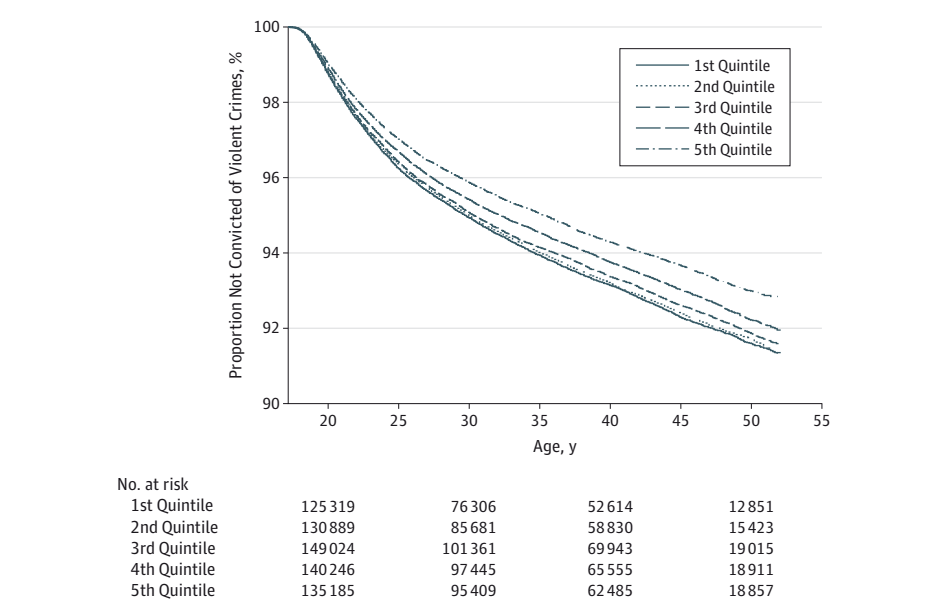
^c n = 709 044.

Table 2. Rates of Violent and Nonviolent Criminality and Assault and Unintentional Injuries by Quintiles of Resting Heart Rate

Variable	Resting Heart Rate Quintiles (Beats/min)					Total Sample
	1st (35-60)	2nd (61-67)	3rd (68-74)	4th (75-82)	5th (83-145)	
Men, No.	132 595	137 117	155 687	145 354	139 511	710 264
Violent crime						
Convictions, No.	7634	8076	9163	8146	7074	40 093
Person-years at risk	2 237 629	2 444 727	2 862 720	2 711 143	2 612 988	12 869 207
Rate (95% CI) per 10 000 person-years at risk	34 (33-35)	33 (32-34)	32 (31-33)	30 (29-31)	27 (26-28)	31 (31-31)
Nonviolent crime						
Convictions, No. ^a	19 398	20 597	23 563	21 594	19 102	104 254
Person-years at risk	1 868 486	2 032 506	2 381 334	2 267 204	2 220 691	10 770 221
Rate (95% CI) per 10 000 person-years at risk	104 (102-105)	101 (100-103)	99 (98-100)	95 (94-97)	86 (85-87)	97 (96-97)
Assaults						
Treatments and deaths owing to assaults, No.	3690	3697	3954	3470	3047	17 858
Person-years at risk	2 313 934	2 529 226	2 963 510	2 800 945	2 689 264	13 296 879
Rate (95% CI) per 10 000 person-years at risk	16 (15-16)	15 (14-15)	13 (13-14)	12 (12-13)	11 (11-12)	13 (13-14)
Unintentional injuries						
Treatments and deaths owing to unintentional injuries, No.	48 365	48 173	53 014	47 055	41 694	238 301
Person-years at risk	1 938 697	2 152 060	2 546 534	2 434 755	2 373 870	11 445 916
Rate (95% CI) per 10 000 person-years at risk	249 (247-252)	224 (222-226)	208 (206-210)	193 (192-195)	176 (174-177)	208 (207-209)

^a Among men not convicted of violent crimes.

Figure. Kaplan-Meier Survival Curves for Violent Criminality by Quintiles of Resting Heart Rate



Quintiles of resting heart rate (beats/min) were first: 35-60; second, 61-67; third, 68-74; fourth, 75-82; and fifth, 83-145. Resting heart rate was measured at a mean (SD) age of 18.2 (0.5) years at conscription testing. Follow-up started from conscription and lasted until the first violent criminal conviction, emigration, death, or end of register coverage (December 31, 2009), whichever occurred first. The analysis included men who were born in Sweden between January 1, 1958, and December 31, 1991.

Table 3. Cox Regression Models for Violent and Nonviolent Criminality and for Assault and Unintentional Injuries

RHR Quintiles (Beats/min)	Hazard Ratio (95% CI) ^a			
	Model Adjusted for Birth and Conscription Years	Model Additionally Adjusted for Height, Weight, BMI, and DBP	Model Further Adjusted for Cognitive Ability, Psychiatric Morbidity, and Childhood SES	Model Adjusted for All Covariates and Cardiorespiratory Fitness ^b
Violent crime				
1st (35-60)	1.24 (1.20-1.28)	1.28 (1.23-1.32)	1.39 (1.35-1.44)	1.49 (1.44-1.55)
2nd (61-67)	1.21 (1.18-1.25)	1.25 (1.21-1.29)	1.33 (1.29-1.38)	1.39 (1.34-1.44)
3rd (68-74)	1.19 (1.15-1.22)	1.21 (1.17-1.25)	1.27 (1.24-1.32)	1.32 (1.27-1.36)
4th (75-82)	1.11 (1.08-1.15)	1.13 (1.09-1.16)	1.16 (1.12-1.20)	1.19 (1.15-1.23)
5th (83-145)	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]
Nonviolent crime				
1st (35-60)	1.20 (1.17-1.22)	1.21 (1.18-1.23)	1.25 (1.23-1.28)	1.33 (1.30-1.36)
2nd (61-67)	1.17 (1.15-1.19)	1.18 (1.15-1.20)	1.21 (1.19-1.24)	1.26 (1.23-1.29)
3rd (68-74)	1.14 (1.12-1.17)	1.15 (1.13-1.17)	1.18 (1.15-1.20)	1.20 (1.18-1.23)
4th (75-82)	1.10 (1.08-1.12)	1.10 (1.08-1.13)	1.12 (1.10-1.14)	1.13 (1.10-1.15)
5th (83-145)	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]
Assault injuries				
1st (35-60)	1.31 (1.25-1.38)	1.34 (1.28-1.41)	1.39 (1.33-1.46)	1.41 (1.33-1.49)
2nd (61-67)	1.27 (1.21-1.33)	1.29 (1.22-1.35)	1.32 (1.26-1.39)	1.30 (1.23-1.38)
3rd (68-74)	1.19 (1.14-1.25)	1.21 (1.15-1.27)	1.23 (1.18-1.29)	1.22 (1.16-1.29)
4th (75-82)	1.10 (1.05-1.16)	1.11 (1.06-1.17)	1.13 (1.08-1.19)	1.09 (1.03-1.15)
5th (83-145)	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]
Unintentional injuries				
1st (35-60)	1.36 (1.34-1.38)	1.37 (1.35-1.39)	1.39 (1.38-1.41)	1.31 (1.29-1.33)
2nd (61-67)	1.26 (1.25-1.28)	1.27 (1.25-1.29)	1.29 (1.27-1.30)	1.23 (1.21-1.25)
3rd (68-74)	1.20 (1.18-1.22)	1.21 (1.19-1.22)	1.22 (1.20-1.23)	1.18 (1.16-1.20)
4th (75-82)	1.11 (1.10-1.13)	1.11 (1.10-1.13)	1.12 (1.10-1.13)	1.09 (1.08-1.11)
5th (83-145)	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]

Abbreviations: BMI, body mass index; DBP, diastolic blood pressure; RHR, resting heart rate; SES, socioeconomic status.

^a All hazard ratios, $P < .001$.

^b Data on cardiorespiratory fitness available for 572 610 men.

Table 4. Cox Regression Models for Specific Violent and Nonviolent Types of Crime

RHR Quintiles (Beats/min)	Hazard Ratio (95% CI) ^a	
	Model Adjusted for Birth and Conscriptioin Years	Model Adjusted for All Covariates ^b
Severe violent crime^c		
1st (35-60)	1.29 (1.21-1.37)	1.67 (1.55-1.79)
2nd (61-67)	1.28 (1.20-1.36)	1.50 (1.40-1.61)
3rd (68-74)	1.25 (1.17-1.32)	1.43 (1.34-1.53)
4th (75-82)	1.15 (1.08-1.23)	1.25 (1.17-1.34)
5th (83-145)	1 [Reference]	1 [Reference]
Less severe violent crime in men with no convictions for severe violence^d		
1st (35-60)	1.22 (1.17-1.27)	1.42 (1.36-1.49)
2nd (61-67)	1.19 (1.15-1.24)	1.36 (1.30-1.42)
3rd (68-74)	1.15 (1.11-1.19)	1.26 (1.21-1.31)
4th (75-82)	1.10 (1.06-1.14)	1.17 (1.12-1.22)
5th (83-145)	1 [Reference]	1 [Reference]
Sexual crime in men with no convictions for nonsexual violent crime		
1st (35-60)	0.95 (0.80-1.14)	1.06 (0.87-1.30)
2nd (61-67)	1.04 (0.88-1.24)	1.17 (0.97-1.41)
3rd (68-74)	1.02 (0.86-1.20)	1.09 (0.91-1.30)
4th (75-82)	1.14 (0.97-1.34)	1.19 (1.00-1.41)
5th (83-145)	1 [Reference]	1 [Reference]
Drug-related crime in men with no convictions for violent crime		
1st (35-60)	1.19 (1.15-1.23)	1.43 (1.38-1.49)
2nd (61-67)	1.14 (1.11-1.18)	1.31 (1.26-1.36)
3rd (68-74)	1.13 (1.09-1.16)	1.23 (1.19-1.28)
4th (75-82)	1.07 (1.04-1.11)	1.12 (1.08-1.16)
5th (83-145)	1 [Reference]	1 [Reference]
Property crime in men with no convictions for violent crime		
1st (35-60)	1.20 (1.15-1.24)	1.43 (1.37-1.49)
2nd (61-67)	1.17 (1.13-1.22)	1.32 (1.27-1.37)
3rd (68-74)	1.17 (1.12-1.21)	1.27 (1.22-1.31)
4th (75-82)	1.10 (1.06-1.15)	1.14 (1.10-1.19)
5th (83-145)	1 [Reference]	1 [Reference]
Traffic crime in men with no convictions for violent crime		
1st (35-60)	1.18 (1.15-1.21)	1.28 (1.25-1.32)
2nd (61-67)	1.16 (1.13-1.19)	1.23 (1.20-1.26)
3rd (68-74)	1.14 (1.11-1.17)	1.18 (1.15-1.21)
4th (75-82)	1.10 (1.08-1.13)	1.12 (1.09-1.15)
5th (83-145)	1 [Reference]	1 [Reference]

Abbreviation: RHR, resting heart rate.

^a Hazard ratios for sexual crimes, $P > .05$; all other hazard ratios, $P < .001$.^b Adjusted for birth and conscription years, height, weight, body mass index, diastolic blood pressure, cognitive ability, psychiatric morbidity, childhood socioeconomic status, and cardiorespiratory fitness.^c Severe violent crimes (10 911 convictions) were associated with custodial sentences (imprisonment, forensic psychiatric inpatient care, or closed institutional youth care).^d Less-severe violent crimes (27 325 convictions) were not associated with custodial sentences.**Association With Criminality and With Injuries Owing to Assaults and Unintentional Injuries**

Table 3 gives results of the Cox proportional hazards regression models in the full sample. Having a lower RHR predicted an increased hazard of violent criminality. Compared with men in the highest quintile of the RHR distribution (RHR ≥ 83 beats/min), those in the lowest quintile (RHR ≤ 60 beats/min) had a 24% higher hazard of violent crimes when only birth and conscription years were adjusted for (hazard ratio [HR], 1.24; 95% CI, 1.20-1.28). Adjusting for physical and cardiovascular covariates in the second model (HR, 1.28; 95% CI, 1.23-1.32) and for psychiatric morbidity, IQ, and childhood SES in the third model (HR, 1.39; 95% CI, 1.35-1.44) resulted in even higher HRs. Adjustment for cardiorespiratory fitness in the fourth model did not reduce the associations (HR, 1.49; 95% CI, 1.44-1.55). Associations with nonviolent criminality were similar but somewhat weaker, whereas associations with assault and accident-related injuries were of the same magnitude as those for violent crimes.

Association With Subtypes of Crime

Results for specific types of crime are given in **Table 4**. Adjusting for all covariates, low RHR was a stronger predictor of severe than less severe violence (HR, 1.67; 95% CI, 1.55-1.79 vs HR, 1.42; 95% CI, 1.36-1.49). With the exception of sexual crimes, the risk for all types of crime was higher among men with a lower RHR. Age at first violent conviction was a mean of 0.32 (95% CI, 0.54-0.10) years lower for men in the lowest RHR quintile compared with those in the highest quintile (eTable 1 in the [Supplement](#)).

Sensitivity Analyses

In sensitivity analyses, the observed associations with RHR were not affected by excluding men with convictions before conscription, excluding those who were convicted of crimes after age 30 years, or excluding conscription years with poor coverage for RHR data (eTable 2 in the [Supplement](#)). Comparison of men with and without RHR data revealed no systematic differences (eTable 3 in the [Supplement](#)). Analyses using SBP instead of RHR replicated the association with violent and nonviolent crimes, as well as with assault injuries (eTable 4 in the [Supplement](#)). Adjusting for all covariates, men in the lowest SBP quintile (SBP < 120 mm Hg) had a 38% (95% CI, 34%-42%) higher hazard of violent crime than men in the highest SBP quintile (SBP ≥ 140 mm Hg). The correlation between RHR and SBP was moderate ($\rho = 0.25$; 95% CI, 0.25-0.25).

Discussion

In a nationwide sample of more than 700 000 men, we found that lower RHR in late adolescence predicts an increased risk of violent criminality in adulthood, confirming findings from previous smaller studies on RHR as a predictor of adult criminal behavior.¹⁰⁻¹³ After taking physical, cardiovascular, psychiatric, cognitive, and socioeconomic effects into account, the effect increased, resulting in a 49% higher risk among men with the lowest RHR as compared with those with the highest RHR.

Our results confirm that, in addition to being associated with aggressive and antisocial outcomes in childhood and adolescence,^{6,7} low RHR increases the risk for violent and non-violent antisocial behaviors in adulthood. Notably, our results present population-based estimates from a sample that is more than 100 times larger than the combined samples used in earlier meta-analyses of children and adolescents. In addition, our findings are longitudinal, whereas earlier evidence comes mostly from cross-sectional studies, thereby reducing the likelihood that the results are owing to criminal behavior leading to low RHR.

To our knowledge, no previous study has tested whether low RHR also predicts non-antisocial behavioral outcomes whose risk might be elevated owing to risk taking, as would be predicted by the main theoretical accounts of the association between RHR and antisocial behavior.^{5,8,9} We hypothesized that low response to fear or stimulation-seeking tendencies would increase the risks of being exposed to assault and unintentional injuries. Official register data of injury-related medical treatments and deaths confirmed that these outcomes were indeed predicted by RHR.

Our findings on the severity of violence and specific types of crime are also novel. Low RHR was a stronger predictor of severe than of less-severe violence. In addition to the association with violence, lower RHR predicted an increased risk for different types of crime, with the exception of sexual crimes. In line with previous studies,¹⁰ our primary analysis combined nonsexual and sexual violent crimes. The finding that RHR did not predict sexual crimes in men without nonsexual violent crimes is interesting, and future studies should aim at clarifying the separate physiological risk factors for sexual and violent crimes.

Our findings are compatible with the theoretical interpretations of low RHR reflecting low arousal or low response to fear. In the low arousal theory, antisocial behavior, including violence, is viewed as stimulating for some individuals. This view is supported by the findings that stimulation-seeking tendencies are associated with aggressive and risk-taking behaviors.^{14,21} The fearlessness theory, on the other hand, is based on the assumption that although RHR is measured at physical rest, it indexes a physiological reaction to a mildly stressful testing situation.⁵ It is supported by studies using other autonomic measures in manipulated experimental con-

ditions: antisocial children and adolescents are characterized by reduced fear conditioning as indexed by skin conductance and eye blink startle responses to aversive stimuli.^{22,23} Two studies of adolescents reported stimulation seeking as a possible mediator in the association between RHR and aggression.^{24,25} The present data, however, could not differentiate between the 2 theoretical accounts.

Furthermore, individual differences in heart rate are influenced by genetic differences,^{26,27} and at least 1 twin study has found low RHR and antisocial behavior to be genetically correlated in childhood.²⁸ Understanding the genetic and environmental mechanisms linking low RHR with the risk for antisocial behavior should be a major goal for future research.

Our results should be considered in combination with some limitations. First, our study included only men, and the results may not be generalizable to women. Second, officially registered criminal convictions were studied, which could have biased the results because not all violent and nonviolent criminal acts result in convictions. However, it is unclear how RHR might be related to the risk of being convicted, and the analyses were adjusted for factors such as IQ, SES, and psychiatric morbidity, which could influence the likelihood of convictions. Furthermore, the observed associations with inpatient and outpatient treatments and deaths owing to injuries supported the validity of the crime data. Third, RHR data were available for only approximately half the conscripted cohorts of men. Men with missing RHR data were not found to differ systematically from those with RHR data, and the analyses were repeated with similar results using SBP, which was available for a much larger sample.

Conclusions

Among Swedish men, lower RHR in late adolescence predicted an increased likelihood of committing violent and nonviolent crimes, being exposed to assault, and unintentional injuries. The associations were not explained by physical, cardiovascular, psychiatric, cognitive, or socioeconomic factors. Resting heart rate and other autonomic measures merit further study in the development and prevention of violence and antisocial behavior.

ARTICLE INFORMATION

Submitted for Publication: February 10, 2015; final revision received May 27, 2015; accepted May 28, 2015.

Published Online: September 9, 2015.
doi:10.1001/jamapsychiatry.2015.1165.

Author Contributions: Dr Latvala had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: All authors.

Acquisition, analysis, or interpretation of data:

Latvala, Kuja-Halkola, Almqvist, Lichtenstein.

Drafting of the manuscript: Latvala.

Critical revision of the manuscript for important intellectual content: All authors.

Statistical analysis: Latvala, Kuja-Halkola, Lichtenstein.

Obtained funding: Latvala, Almqvist, Larsson, Lichtenstein.

Administrative, technical, or material support: Lichtenstein.

Study supervision: Larsson, Lichtenstein.

Conflict of Interest Disclosures: None reported.

Funding/Support: This study was supported in part by grant 2012-1678 from the Swedish Research Council for Health, Working Life and Welfare; grant 2011-2492 from the Swedish Research Council; grant 340-2013-5867 from the Swedish Research Council through the Swedish Initiative for Research on Microdata in the Social and Medical Sciences; grant 277209 from the Academy of Finland; and a

grant from the Alfred Kordelin Foundation. The research leading to these results has received funding from the European Union Seventh Framework Programme under grant agreement 602768.

Role of the Funder/Sponsor: The funding sources had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

REFERENCES

1. U.S. Department of Justice. Crime in the United States, 2013. <https://www.fbi.gov/stats-services/crimestats>. Accessed February 10, 2015.

2. Corso PS, Mercy JA, Simon TR, Finkelstein EA, Miller TR. Medical costs and productivity losses due to interpersonal and self-directed violence in the United States. *Am J Prev Med*. 2007;32(6):474-482.
3. Biglan A, Taylor TK. Why have we been more successful in reducing tobacco use than violent crime? *Am J Community Psychol*. 2000;28(3):269-302.
4. Glenn AL, Raine A. Neurocriminology: implications for the punishment, prediction and prevention of criminal behaviour. *Nat Rev Neurosci*. 2014;15(1):54-63.
5. Raine A. Annotation: the role of prefrontal deficits, low autonomic arousal, and early health factors in the development of antisocial and aggressive behavior in children. *J Child Psychol Psychiatry*. 2002;43(4):417-434.
6. Lorber MF. Psychophysiology of aggression, psychopathy, and conduct problems: a meta-analysis. *Psychol Bull*. 2004;130(4):531-552.
7. Ortiz J, Raine A. Heart rate level and antisocial behavior in children and adolescents: a meta-analysis. *J Am Acad Child Adolesc Psychiatry*. 2004;43(2):154-162.
8. Loeber R, Pardini D. Neurobiology and the development of violence: common assumptions and controversies. *Philos Trans R Soc Lond B Biol Sci*. 2008;363(1503):2491-2503.
9. van Goozen SH, Fairchild G, Snoek H, Harold GT. The evidence for a neurobiological model of childhood antisocial behavior. *Psychol Bull*. 2007;133(1):149-182.
10. Wadsworth MEJ. Delinquency, pulse rates and early emotional deprivation. *Br J Criminol*. 1976;16(3):245-256.
11. De Vries-Bouw M, Popma A, Vermeiren R, Doreleijers TA, Van De Ven PM, Jansen LM. The predictive value of low heart rate and heart rate variability during stress for reoffending in delinquent male adolescents. *Psychophysiology*. 2011;48(11):1597-1604.
12. Jennings WG, Piquero AR, Farrington DP. Does resting heart rate at age 18 distinguish general and violent offending up to age 50? findings from the Cambridge Study in Delinquent Development. *J Crim Justice*. 2013;41(4):213-219.
13. Raine A, Venables PH, Williams M. Relationships between central and autonomic measures of arousal at age 15 years and criminality at age 24 years. *Arch Gen Psychiatry*. 1990;47(11):1003-1007.
14. Jonah BA. Sensation seeking and risky driving: a review and synthesis of the literature. *Accid Anal Prev*. 1997;29(5):651-665.
15. Carlstedt B. *Cognitive Abilities—Aspects of Structure, Process and Measurement*. Göteborg, Sweden: Göteborgs Universitet; 2000.
16. Statistics Sweden. Multi-generation register 2009: a description of contents and quality. <http://www.scb.se/en/Finding-statistics/Publications>. Accessed November 10, 2014.
17. Sundström J, Neovius M, Tynelius P, Rasmussen F. Association of blood pressure in late adolescence with subsequent mortality: cohort study of Swedish male conscripts. *BMJ*. 2011;342:d643.
18. Beckley AL, Kuja-Halkola R, Lundholm L, Långström N, Frisell T. Association of height and violent criminality: results from a Swedish total population study. *Int J Epidemiol*. 2014;43(3):835-842.
19. Svedenkrans J, Henckel E, Kowalski J, Norman M, Bohlin K. Long-term impact of preterm birth on exercise capacity in healthy young men: a national population-based cohort study. *PLoS One*. 2013;8(12):e80869.
20. Liu L, Mizushima S, Ikeda K, Nara Y, Yamori Y; Cardiovascular Disease and Alimentary Comparison Study Group. Resting heart rate in relation to blood pressure: results from the World Health Organization-Cardiovascular Disease and Alimentary Comparison study. *Int J Cardiol*. 2010;145(1):73-74.
21. Wilson LC, Scarpa A. The link between sensation seeking and aggression: a meta-analytic review. *Aggress Behav*. 2011;37(1):81-90.
22. Fairchild G, Van Goozen SH, Stollery SJ, Goodyer IM. Fear conditioning and affective modulation of the startle reflex in male adolescents with early-onset or adolescence-onset conduct disorder and healthy control subjects. *Biol Psychiatry*. 2008;63(3):279-285.
23. Syngelaki EM, Fairchild G, Moore SC, Savage JC, van Goozen SH. Affective startle potentiation in juvenile offenders: the role of conduct problems and psychopathic traits. *Soc Neurosci*. 2013;8(2):112-121.
24. Portnoy J, Raine A, Chen FR, Pardini D, Loeber R, Jennings JR. Heart rate and antisocial behavior: the mediating role of impulsive sensation seeking. *Criminology*. 2014;52(2):292-311.
25. Sijtsma JJ, Veenstra R, Lindenberg S, et al. Mediation of sensation seeking and behavioral inhibition on the relationship between heart rate and antisocial behavior: the TRAILS study. *J Am Acad Child Adolesc Psychiatry*. 2010;49(5):493-502.
26. Tuvblad C, Isen J, Baker LA, Raine A, Lozano DI, Jacobson KC. The genetic and environmental etiology of sympathetic and parasympathetic activity in children. *Behav Genet*. 2010;40(4):452-466.
27. Van Hulle CA, Corley R, Zahn-Waxler C, Kagan J, Hewitt JK. An exploration of the genetic and environmental etiology of heart rate in infancy and middle childhood. *Twin Res*. 2000;3(4):259-265.
28. Baker LA, Tuvblad C, Reynolds C, Zheng M, Lozano DI, Raine A. Resting heart rate and the development of antisocial behavior from age 9 to 14: genetic and environmental influences. *Dev Psychopathol*. 2009;21(3):939-960.